

REVIEW OF THE PRESENT SITUATION ON LASER RESEARCH

E.David

FACILITY FORM 602	N66 33688	
	(ACCESSION NUMBER)	(THRU)
	27	1
	(PAGES)	(CODE)
	(NASA CR OR TMX OR AD NUMBER)	(CATEGORY)

Translation of "Übersicht über die derzeitige Situation
auf dem Lasergebiet",
Institut Franco-Allemand de Recherches de Saint-Louis,
Note Technique T 21/63. October 2, 1963.

GPO PRICE \$ _____

CFSTI PRICE(S) \$ _____

Hard copy (HC) \$2.00

Microfiche (MF) .50

ff 653 July 65

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON JUNE 1966

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A general review over the papers presented at the 1963 New York Symposium on Optical Masers is given, including theoretical background and future application of lasers. Laser materials, types of lasers (solid-state, gas, semiconductor, etc.), control of laser emission, types of modulation (internal and external), excitation methods, and practical applications are reviewed. The principle of continuous and spike emission is explained, without radically new interpretation.

Summary

Based on the "Symposium on Optical Masers" in New York, April 16 - 19, 1963, a general view is given over the entire field of lasers. Partial application fields discussed here include:

Theoretical principles: Forced emission, laser-adapted terms, nonlinear polarization.

Laser systems: Principle of the optical resonant cavity, gas lasers, solid-state lasers, semiconductor lasers, method of excitation.

Function of lasers: Gain and loss in excitation and light energy; differential equation, time-invariant radiation and radiation in spikes.

Control of laser emission: Possible methods, power requirement, and

* Numbers in the margin indicate pagination in the original foreign text.

performance.

Demodulation: VHF modulated light, as corresponding reversal of modulation of laser light.

Application of lasers.

Preliminary Remarks

This summary report is based on the "Symposium on Optical Masers" sponsored by the Polytechnic Institute of Brooklyn, in New York on April 16 - 19, 1963. Since this Symposium was attended by leading researchers in the laser field from all over the world, the state of the art as of that year no doubt was adequately covered. This assumption was also substantiated by papers on lasers presented at the Physicists Meeting in Hamburg on Sept. 9, 1963. The only novel aspect was a light source arrangement demonstrated at the Meeting. /6

The significance attributed to the New York Symposium was evident not only from the large number of participants (about 1200) but also from the introductory address, given, among others, by three top-level science and research directors of the USA Air Force, Navy, and Army as well as by the presidents of the IRE (Institute of Radio Engineers) and the Optical Society of America.

The following excerpt is a scientifically grouped review which, so far as necessary, also contains some of the basic principles stipulated in the Symposium. Here, we will not give a list of the 47 individual papers with their confusing multiplicity of specific individual facts. This will be done in the regular "Proceedings of the Symposium" to be published at the end of 1963*.

1. Theoretical Principles

The theoretical principles were covered mainly in three introductory papers

* John Wiley & Sons, Inc. N.Y., 1963.

by Kallman (New York), Bloembergen (Harvard University), and Wolf (Rochester).

As is known, the fundamental effect of a laser is forced emission, known also as stimulated or induced emission, in contrast to spontaneous emission.

The existence of induced emission had been theoretically proved as early as the very beginnings of quantum theory, based on the general Planck-Einstein formulas for cavity radiation. Without induced emission, the classical Rayleigh-Jeans radiation law is obtained also in the presence of radiation quanta. Conversely, Planck's law necessarily includes, although in a rather indirect manner, the concept of stimulated emission. In 1928, Ladenburg, in 17 studies on negative dispersion, was able to demonstrate the existence of stimulated emission in a somewhat more direct manner.

The existence of induced emission is only one of the prerequisites for lasers. Another one is to cause the induced emission to predominate over the spontaneous emission which latter increases with ν^3 . For this, energy terms are necessary in which the transition probability to lower terms is infinitesimal or, in other words, in which all normal transitions are forbidden.

Whereas, for allowed transitions, the transition probability can be theoretically computed with satisfactory accuracy, a calculation for such forbidden transitions becomes unreliable and inaccurate. Just as great will be the inaccuracy in calculating nonradiative transitions that might possibly compete with radiative transitions. Thus, for spectroscopically obtained terms with suitable properties, one can only predict the possibility but never the presence of a laser-suitable transition.

On the other hand, a theoretical treatment of the excitation of a laser level is no problem, provided that this excitation takes place by optical pumping over the detour of a higher level. Conversely, no final explanation has

been found for the selective excitation of laser levels by electron collision, as they are specifically observed in gas lasers.

The geometric-optical, wave-optical, and diffraction-optical propagation behavior of laser light does not differ from that of ordinary thermal light. /8 For this reason, the theory cannot contribute anything new to this particular field. In the theory of wave optics, fluctuation phenomena are generally neglected, which really means that one has always been calculating with laser light. From this it follows directly that, for the operation of optical instruments, laser light and thermal light are equivalent since the fluctuation phenomena play no role in the theory of optical instruments.

The decisive difference lies in the thermodynamic behavior. The initial state in a laser is an excitation state (thermally not attainable, even at arbitrarily high temperatures) at which a higher level is always more heavily populated than a lower level. This eliminates the thermodynamic restriction that, on concentration of the light, the black radiation density of the temperature of the initial radiator must not be exceeded. Radiation densities can be reached at which the electric field strength of the light wave has an order of magnitude of 10^8 v/cm. This means a radiation current of the order of 1000 kw through a slit of 1μ diameter.

Because of the high electromagnetic field strength, transparent matter can be nonlinearly polarized in laser light.

This leads to the production of harmonics, light of double and triple frequency, and generation of sum and difference frequencies on mixing with thermal light. This effect, which is quite impossible to obtain without laser light and therefore has usually been disregarded in the theory, has been fully realized through the invention of lasers (up to 20% transformation to double frequency).

For this reason, the respective theory has been developed in more detail.

Furthermore, the theory of coherence and fluctuation phenomena which, /9
until then, had been adapted to the conditions of thermal light required a
generalization. In thermal light, no coherence exists between light emitted by
various segments of a luminescent area and also no time-coherence over periods
that are long with respect to the testing period.

2. Laser Systems

An essential component of most lasers is a mirror arrangement which reflects
and re-reflects light and thus increases the light current density to the re-
quired magnitude. Such an optical arrangement, in basic principle, always cor-
responds to that shown in Fig.1.

Two lenses with reflectors in their focal planes reflect parallel light
beams into themselves, no matter whether such a beam is exactly axisymmetric or
slightly inclined to the axis. At least geometrically, no light is lost in this
manner.

In practical use, the lenses are replaced by concave mirrors, supplemented
by reflections on plane mirrors and virtual images. However, this changes
nothing on the basic principle. Even a simple arrangement consisting of two
parallel mirrors can be considered a limiting case of Fig.1, with infinitely
many reflections and a concave mirror radius near infinite.

Gas lasers have the advantage that the setup can be arbitrary so far as
form and size are concerned. Such arbitrariness is even a prerequisite, since
the excitation density basically remains low. In competition with stimulated
emission, gas-kinetic collisions of the second kind remove energy from the meta-
stable initial laser level. Only at low gas density (pressure order of magni-

tude, torr) will the collisions not remove an excessive amount of energy. /10
Even an increase in the exciting electron current will not increase the excitation density by much; this density always passes a maximum. Therefore, the size of the system (length, about 1 m) must be adjusted such that each photon, during its lifetime in the laser volume, induces - on the average - the emission of exactly one new photon. In this case, equilibrium will be established between excitation on the one hand and losses and continuous laser emission on the other hand. The emissivity is here located in the milliwatt range. In addition to electric excitation, attempts were also made to obtain excitation by chemiluminescent gas reactions. However, actual laser emissions have never been obtained in this manner.

In solid-state lasers, the excitable atoms, usually rare earth ions, are solidly built into the crystal lattice. This eliminates excitation losses by collisions. In addition, the excitation density, in order of magnitude, is greater than in the gas. The embedding crystal lattice strongly affects the optically active atoms. For this reason, lattice defects act as irregular (for example, frequency-detuning) effects. In addition, they interfere with the ray path in the laser, acting as optical inhomogeneities. Both phenomena have the consequence that the threshold value of the excitation density, at which the laser function sets in, is greatly raised. In the case of apparently equal ruby crystals, continuous laser emission is readily obtained with some while others, in turn, have threshold values of considerable magnitude. Naturally, such a poorly defined differing behavior interferes greatly with practical application. For this reason, General Electric and other Companies, in their manufactured laser systems in most cases replace the crystals by laser rods of gadolinium-doped glass which are much easier to produce. However, the performance of such

lasers is not as high as to make further development of more efficient crystals superfluous. /11

The xenon flash tubes, furnishing the pump light, are arranged in a specular casing around the laser rod. It is preferable, as reported by Röss (Siemens & Halske, Munich) at the Physicists Meeting in Hamburg, to make use of the fact that an ellipsoid of revolution is able to map the two segments between focus and vertex as a whole at one-to-one correspondence. This permits a more uniform illumination of the laser rod and prevents the interfering effect of heat and magnetic field of the lamp.

The sharply defined wavelength, emitted by a laser, is determined also by the random and relatively inconstant optical resonance frequencies of the mirror system. To obtain a frequency standard dependent only on the atomic size, Schawlow of Stanford University made an attempt to obtain laser action with large crystals, using at most a terminal mirroring.

Also optical transitions in transparent semiconductors can be used for lasers. In question are transitions between conduction and valence band, between conduction band and acceptors, between donors and valence band, between donors and acceptors, transitions with and without pulse variation, i.e., with and without simultaneous emission of a photon. Until now, only one system has been realized: laser emission in the region of a p-n junction in GaAs, produced by a transition between conduction band and acceptors, whose frequency is located in the near infrared. The radiating volume, in the design in question here, has a magnitude of only $3 \mu \cdot 0.1 \text{ mm} \cdot 0.5 \text{ mm}$. The power consumption is correspondingly low, being of the order of 1 w. However, of interest is the efficacy /12 of conversion of electric energy into light energy. Counting only the exciting current above the threshold value, an efficiency up to 50% is obtained. In the

vanishingly small active volume, the excitation density is so high that laser emission takes place without the use of light-current amplifying mirrors.

3. Laser Materials

For gas lasers, all inert gases have been investigated; until now, about 160 different laser frequencies in the infrared were found up to wavelengths of $28\ \mu$. It is by no means impossible that also longer wavelengths are emitted as laser radiation, since the detector used until now had a sensitivity only to $30\ \mu$.

In contrast to thermal infrared radiation, the intensity of these infrared radiations is by several orders higher so that, from the scientific and practical viewpoint, entirely new perspectives are opened for the infrared region. This fills an essential part of the gap between infrared and microwaves. Hopefully, this gap will be completely filled by lasers, either directly or indirectly over arrangements of the waveguide type.

Other gases, such as readily fluorescent organic gases, may be in question although they are not as convenient as the noble gases which can be excited by electron collision.

For solid-state lasers, it is mainly the rare earth ions that have sharp transitions with suitably low transition probabilities. These ions may be incorporated into the lattice either in the divalent or trivalent form, which makes a considerable difference in the spectra.

In view of their possible use for laser purposes, all spectra of the rare earth metals were recorded anew. On the basis of only the spectra or term schemes, it cannot be reliably predicted which transitions might be suitable for laser action since the host crystal into which the ions are incorporated has a

major influence on the transition probabilities. To this must be added the influence of other atoms in the crystal lattice, specifically of alkali atoms. These re-establish the equilibrium when trivalent rare earth ions are incorporated into a divalent crystal. A crystal substance of excellent suitability for lasers is calcium tungstate; however, the growing of good crystals is still an unsolved problem.

Other substances in question are various types of glass as well as plastics and liquids. The two latter can be mixed with fluorescing organic molecules as radiating substance. Even in these more or less amorphous embeddings, the radiating atoms or molecules show a slightly differing behavior depending on the cementing substance. Specifically the threshold value of the excitation density is affected.

In view of the great multiplicity of the possibilities and the usually considerable difficulty of incorporating the substances into an optically homogeneous low-impurity lattice, with uniform distribution of the desired atoms, it must be expected that considerable time will elapse before all possibilities have been thoroughly checked and before reliable fabricating methods for optimum materials have been developed.

Accordingly, no predictions can be made on the possible results. Might it be possible to cover the entire visible region with laser frequencies and might uniform as well as spike emission be obtainable at will at the various frequencies? Up to what power can this be obtained? What will be the most suitable /14 and optimum laser substances in a few years from now? These and other questions are still entirely open.

The possibilities for semiconductor lasers are just as vague at present.

4. Function of Lasers

a) Ideal Function

A photon, traveling in the laser light beam, will be absorbed by an atom in the lower state of the laser transition with the same probability as it will stimulate the emission of a second photon traveling in the same direction and at equal phase, for an atom in the upper state. To permit an intensification of the laser light, more than 50% of the atoms capable of laser transition must be in the upper state. Naturally, this applies only to the three-level laser in which the lower state simultaneously is the ground state. In a four-level laser, the lower state is a practically unoccupied level with a high transition probability to the ground state. Since, in the four-level scheme, the energy spacing between initial and ground level is tripartite, this scheme will be of significance only for infrared laser transitions and probably will never be of importance for transitions in the visible region.

Alone the maintenance of the 50% excitation state of a three-level laser requires a certain pump power, i.e., a continuous transport of atoms into the upper state. The following losses must be covered here:

- 1) spontaneous emission;
- 2) nonradiative transitions.

Spontaneously emitted photons travel almost always in the wrong direction /15 and leave the laser. For this reason, they must be considered a loss despite the fact that one or several might form the origin of the laser emission. Non-radiative transitions may be of manifold type. In a gas laser, the most important role is played by gas-kinetic collisions of the second kind and collisions between excited atoms and exciting electrons, leading to a cancelation of the excitation itself. These two phenomena limit the gas pressure and the

exciting electron current and thus also the overall performance of the laser. The losses due to spontaneous emission and nonradiative transitions are proportional to the number of excited atoms.

A laser light beam, reflected back and forth between the mirrors of the laser, undergoes losses proportional to itself, produced by

- 3) absorption during reflection;
- 4) effective light, transmitted through a semitransparent mirror;
- 5) light diffracted along the mirror edges;
- 6) absorption within the laser material (other than that produced by the laser transition itself);
- 7) scattering within the laser material and on the mirror surfaces.

The losses 3) to 7) necessitate an excitation 50% above the defined amount, so as to just about permit an increase in photons within the laser, by stimulated emission.

This maximum required excitation for initiation of the laser action is coordinated with certain losses as mentioned under 1) and 2). If the pump power is higher, a state of equilibrium will be established with a certain light beam, reflected back and forth between the mirrors, and a certain transmitted effective light beam.

Expressed mathematically, this approach to equilibrium reads as follows: /16

$$\frac{dw}{dt} = B(n_2 - n_1) w - Dw, \quad (1)$$

$$\frac{dn_2}{dt} = -B(n_2 - n_1) w - An_2 + Pn_1, \quad (2)$$

$$n_1 + n_2 = N \quad (3)$$

where w = number of photons in the reflected and re-reflected light beam;
 n_1 = number of atoms in the lower laser level;
 n_2 = number of atoms in the upper laser level;

N = total number of atoms in which laser transition is possible;

t = time;

A, B, D, P = constants.

The term $B(n_2 - n_1)w$ represents the difference between the induced-emitted photons and the photons absorbed by the lower level of the laser transition. This term also occurs in eq.(2) since, for the emission (absorption) of a photon a decrease (increase) by 1 of the number of atoms in the upper state is necessary. The second term Dw represents the light losses 3) to 7).

In eq.(2), An_2 represents the losses 1) and 2), while Pn_1 contains the excitation produced by pumping. The proportionality with n_1 is the most logical and presumably also the most frequent case. However, this need not necessarily apply. For example, the pump power may increase somewhat at high n_1 or may even asymptotically tend toward a maximum value. However, such fine differences produce no qualitative changes in the laser action.

In the equilibrium case, i.e., at vanishing time derivatives, eqs.(1) - (3) have the solutions: 17

$$n_{1g} = \frac{N}{2} - \frac{1}{2} \frac{D}{B}, \quad n_{2g} = \frac{N}{2} + \frac{1}{2} \frac{D}{B}, \quad (4)$$

$$w_g = \frac{Pn_{1g} - An_{2g}}{D} \quad (5)$$

As a consequence of the homogeneity of eq.(1), the excitation densities, according to eq.(4), become independent of the pump power.

Equations (4) and (5) directly give the case when no laser action can occur. First, at too low a transition probability B and too high an optical loss D , with respect to the given number N of excitable atoms, it might become impossible to obtain $n_1 < 0$, $n_2 > N$. Second, the quantity n_2 , according to eq.(4), definitely prescribes the losses An_2 by spontaneous and nonradiative transitions in

eq.(5). If the pump power Pn_1 does not exceed these losses, $w = 0$ will remain, meaning no laser light will be produced. Incidentally, this proves that practically no changes are produced if, instead of the proportionality $P \propto n_1$, a functional dependence $P(n_1)$ is used.

The ideal case is fairly well realized in gas lasers. The stipulated spatially uniform density of excitation and the uniform density of the emission-stimulating light beam are not applicable here, but the gas-kinetic motion of the excited atoms compensates for this.

b) Emission in "Spikes"

In the case of solid-state lasers, the time-invariant radiation, according to eq.(5) and according to the pump power, is observed only in exceptional cases. In most instances, the radiation takes place in "spikes", i.e., in discrete /18 radiation pulses of about 1 - 30 μsec duration, at time intervals of approximately 100 μsec to several hundred. In height and time intervals, the spikes show a multiple statistically random distribution.

Naturally, this does not interfere with practical application. Therefore, it is desirable to regulate the spikes either by theoretical definition or by experimental control of the light emission.

Experimental data, according to several papers presented at the Symposium, indicate that uniform radiation can be obtained only at a relatively low threshold value, i.e., at low n_2 according to eq.(4) and at relatively high pump power. A discriminating condition, such as an expression derived from the constants of eqs.(1) and (2), could be expected. However, none of the participants in the New York Symposium mentioned such a condition.

The occurrence of spikes could be readily explained if eqs.(1) and (2), at

suitable coefficients would have unstable solutions. However, the equations always furnish solutions whose value is attenuated to the equilibrium values (4) and (5). A typical example for the strongly anharmonic vibration at high amplitude is shown in Fig.2 (computed at the Saint-Louis Institute, but not reported at the Symposium!). From a qualitative viewpoint, calculation and experiment coincide in so far as, under the above-mentioned experimental conditions of continuous radiation, the calculation results in a strongly damped little vibrating or nonvibrating approach to the equilibrium value.

At the Symposium, a Japanese author made an attempt to render eqs.(1) and (2) unstable by introducing a factor $(1 - \epsilon w)$ at B. So long as $\epsilon w \ll 1$, this additional term would be of no significance. However, as soon as $\epsilon w > 1$, the auxiliary term becomes mathematically effective but physically impossible since /19 this would mean that the loss is transformed into a gain.

In two points, the system of equations (1) - (3) does not correspond to reality:

1) The vibration mode of the laser light is never ideal in practical cases, and the density of the light beam is irregularly distributed within the laser material. In addition, the current density of the exciting light and the density of the excitable and excited centers, normally, is not ideal-homogeneously distributed. Specifically, the laser light vibrates in standing waves. In the nodes of these waves, no emission is induced and the excitation persists. Only during a jump to other vibration modes can the excitation decay in the total volume of the laser material. These conditions were experimentally confirmed, for example, by Fabry-Perot frequency analyses of the laser light of a ruby, recorded in streak photographs. These investigations, made at the University of Tokyo, showed statistical light-frequency fluctuations with periods of about

1 μ sec within the individual spike. No decision could be made as to whether this complex statistical process, which is individually not analyzable, might leave eqs.(1) - (3) constant on the average or change them substantially.

2) These continuous-macroscopically derived equations hold for "large" numbers of photons, meaning that they are valid, with qualitatively insignificant deviations, above 5 - 10 photons that are present in the laser in a certain vibration mode. As soon as this infinitesimal beginning has been created, the number of photons, in accordance with the law of exponents, increases up to the peak of the spike to the enormous value of $10^{16} - 10^{20}$. However, this beginning of validity of the continuous equations is preceded by the decisive and true /20 initiation, namely, the step from 0 to 1 photon and the strongly statistical steps from 1 to 2, 3, etc. photons. A considerable influence is exerted here by the fact that, for a photon, the probability of being absorbed is not much less than the probability of production of a second photon by stimulated emission. Thus, in the case of very few photons the probability exists that the chain will break off again.

At first glance, it seems highly improbable that, in the enormous quantity of bright light of the exciting flash tube, focused by the mirror, there should not be a certain number of "correct" photons for initiation of laser emission. However, the number of photons of the proper frequency is not very large in white light, and these photons can reach the correct propagation region in the proper space zone only by highly improbable scattering or diffraction processes. This leaves only the photons spontaneously emitted in the laser material. The numerical values, for a standard small ruby rod, presumably will be of the order of magnitude of:

excited atoms 10^{17}

spontaneously emitted photons	10^{-9} per sec
of this, in the correct solid angle	10^{-9}
of this, in the correct frequency range	10^{-5}
resulting in "correct" photons,	10^5 per sec
i.e., on the average one every 10 μ sec.	

If, at the end of the spike, the laser emission decays to zero photons, it is evident that the next spike will start anew and in a statistically random manner, with a single photon. However, it is still an open question whether, in all cases of the occurrence of spikes, a decay to zero actually takes place in the intervals.

In any case, it is a peculiar fact that, exactly in the technical arrange-^{/21}ment in which the momentarily highest and most concentrated quantities of light occur, individual light quanta play a major and macroscopically detectable role.

5. Control of Lasers

For many practical application purposes, one desires a laser light differing from a chance configuration, meaning that control or modulation of the light is desired. For this, various possibilities exist:

a) External Modulation

It is possible, specifically in the case of gas lasers radiating continuously at low power, to modulate, by electro-optical or magneto-optical means, the light transmitted through the semipermeable mirror.

b) Internal Modulation

Since the laser action is highly sensitive to the resonance quality of the

optical resonant cavity, even a minor modification may have major consequences.

c) Decoupling Modulation

Only a very small fraction of the internal light beam of the laser is permitted to emerge, for example, through a semipermeable mirror. This can be replaced by a modifiable weak decoupling.

External modulation is the simplest in principle. All effects, useful for control of ordinary light, can be used here: Kerr effect, Faraday effect specifically electric birefringence of potassium and ammonium diphosphate crystals (KDP and ADP), multiple reflection Kerr effect on thin ferromagnetic films, 122 periodic diffraction on a standing supersonic field, and - specifically for monochromatic laser light - interference in a Fabry-Perot interferometer whose distance undergoes HF variations due to the transverse vibrations of a quartz crystal. A narrow-band modulation, at frequencies of the order of megacycles, constitutes no problem for almost all of these methods. Conversely, the broadband modulation in the gigacycle range, desirable in communications technology, offers considerable difficulty. This type of modulation requires control powers of the order of kilowatts, which are extremely difficult to dissipate as heat during continuous operation.

In this respect, internal modulation is much more favorable since the optical control cell is allowed to vary only between complete transmittance and an absorption or deflection of at most a few percent of the light beam. Since, for approach to equilibrium, the light must pass the active volume of the laser several times in both directions, the frequency of the internal modulation is restricted to about 10 - 100 mc.

For producing especially strong light pulses, internal modulation is a pre-

requisite. In the blocked state, this type of modulation is able to produce transition of the excitable atoms in the laser, in the overwhelming majority and far beyond eq.(4), to the upper excited state, at least as far as the intensity of the pump light and the losses produced by spontaneous emission etc. permit this. On initiating the laser action at a desired instant of time, the available portion of the stored excitation energy is then emitted in a single short-time spike. Maiman, using large ruby rods, obtained the following values in order of magnitude:

stored energy	1 k-joule	<u>123</u>
emission period	1 μ sec	
peak light current	10^9 w.	

According to Müller (Siemens & Halske, Munich), decoupling modulation is the optimum type for communications and similar purposes, having the lowest energy requirement and the most extensive possibilities with respect to frequency and bandwidth of the modulation. The birefringence of a KDP crystal, controlled between zero and a very low value, will deflect a small portion of the internal laser light beam. Because of the lower limit of zero, this decoupled light still will have 100% modulation.

6. Demodulation of the Light

Whereas transmitter and receiver devices frequently are similar in operating principle, the laser is not suitable at present for use as receiver amplifier.

However, in itself any suitably designed photoelectric cell can be used for reception of microwave-frequency-modulated light.

To eliminate unnecessary noise sources, the absorbing photoelectric effect device and the input amplification should form one compact unit.

In the case of amplitude modulation, the following are in question:

- 1) microwave phototubes that use the photoelectrons directly in a traveling-wave vacuum-tube amplifier;
- 2) microwave photoamplifiers with partitioned emission cathode area;
- 3) peak semiconductor photodiodes which, on heterodyning of the /24 double frequency as pump frequency, are simultaneously able to act as paramps. These types of photodiodes are well matched to the point focusing of the laser light.

Less suitable are photomultipliers and even less so, photoresistances.

In the case of frequency modulation, transverse-wave FM phototubes and birefringent discriminator devices are in question, which permit a transition to amplitude modulation.

Designs, differing in basic principle from lasers, will not be further discussed here.

7. Practical Applications of Lasers

The New York Symposium yielded very few data on the practical use of lasers. Obviously, the laser is still too new for multiple applications going beyond the stage of planning and preliminary experiments. Of course, its applicability as a simple range radar is too trivial to even have been mentioned during the Symposium.

From the medical viewpoint, attempts are made to utilize the ideal focusability of the laser beam for the cutting and punching of minute holes or, at a somewhat lower dose, for coagulating. In cases of retina detachment, thermal light had already been used in earlier days for re-attaching the retina to individual points by coagulation. In this, the lens of the eye itself is used as

the light-focusing system. Naturally, for such purposes the laser is an ideal light source and has been used with success. The effect of laser action on living tissue, in comparison with the effect of equivalent thermal energies used previously, is entirely negligible.

A primarily scientific application is that of a reproduction of the Sagnac test, made by the Sperry Rand Corp. Here, gas-laser beams are made to travel 25 around an area of about 1 m^2 in both directions along the same path, after which the two light beams are brought to beat frequency by reflection from transparent mirrors. This permits a highly accurate measurement of rotational velocities of $2 - 80^\circ/\text{min}$, insensitive to interference by deformation of the light path, from which also the absolute total rotational angle can be integrated. This leads to beat frequencies of $500 - 20,000 \text{ cps}$, in accordance with the formula
$$\Delta f = \frac{4wF}{\lambda L}$$
 (where w is the angular velocity of rotation, F the area circumscribed by the light path, L the length of the light path, and λ the wavelength of the light).

At too low a rotational speed, an interaction of beams traveling in opposite directions has an interfering effect; at too high a velocity, natural vibrations will be set up, with the total number of light waves along the circumscribing light path varying by a factor of 1. For determining a given direction in space, one could obtain a rotation of suitable velocity by mechanical means from which the integrated rotational angle could again be mechanically subtracted.

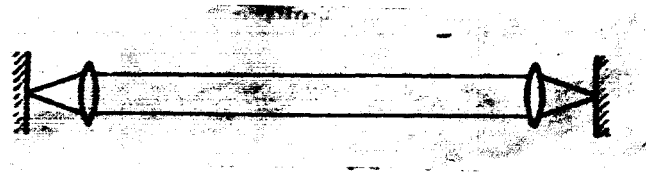


Fig.1 Principle of Laser Optics

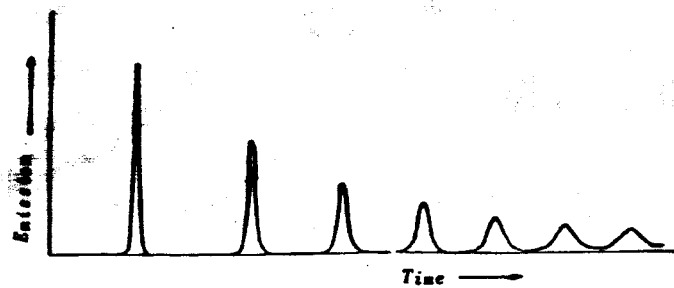


Fig.2 Variation in Emission as a Function of Time (Theoretical)